

A STUDY ON EFFECT OF GEOMETRIC PATTERNS AND MATERIAL ON STRESS DISTRIBUTION IN DENTAL IMPLANT SYSTEM: A 3-DIMENSIONAL FINITE ELEMENT ANALYSIS

NAYANA PRABHU¹, NITHESH NAIK², VATHSALA PATIL^{3*}

UDIT RATHEE⁴ & AMINA BARKALLAH⁵

¹Department of Prosthodontics and Crown & Bridge, Manipal College of Dental Sciences, Manipal,
Manipal Academy of Higher Education, Manipal, Udupi, Karnataka, India

^{2,4}Department of Mechanical and Manufacturing Engineering, Manipal Institute of Technology,
Manipal Academy of Higher Education, Manipal, Udupi, Karnataka, India

³Department of Oral Medicine and Radiology, Manipal College of Dental Sciences, Manipal,
Manipal Academy of Higher Education, Manipal, Udupi, Karnataka, India

⁵Department of Mechanical Engineering, National Engineering School of Bizerte, University of Carthage,
Republic Avenue Amilcar, Tunisia

ABSTRACT

This study investigate the modified implant body design by varying thread pitch, helix angle to study the influence of the parameters on stability and stress distribution at the implant/bone interface, and also identify the optimum implant structure, suitable for reliable rehabilitation and quicker osseointegration under biomechanical loading conditions. The study was classified into three groups: Group 1 (standard pitch), Group 2 (helix angle) and Group 3 (biocompatible material: titanium). A three dimensional finite element model of three variants were designed with the standard pitch group 2.2 mm and single thread, double thread and triple thread, respectively. The results obtained under normal load applied for titanium showed maximum Von Mises stresses at interface of dental implant structure and cortical bone. The results show that the thread pitch and helix angle plays a substantial role in enhancing the implant stability and reducing the bone stress. Moreover, from the biomechanical analysis for the screwed implant structure with thread pitch of 2.2 mm with double thread, proves to be optimal.

KEYWORDS: Dentistry, Implantology, Restoration, Dental Materials & FE Analysis

Received: Jul 04, 2019; **Accepted:** Jul 24, 2019; **Published:** Sep 23, 2019; **Paper Id.:** IJMPERDOCT201966

1. INTRODUCTION

Dental implants have been widely accepted by dental specialists and patients in rehabilitation of tooth, because of its reliable and aesthetic results. The clinical applications of dental implant system is proved to be successful in long term with a survival rate of over 90% [1]. The quality of the jaw bones, design of the implant, implant surface texture, surgical treatment procedures etc. directly relate to the osseointegration and success of the dental implant [2, 3]. The implant diameter, length of the implant, geometric patterns and material of implant are the key parameters that play an important role in implant design process, as they significantly influence the stability and micro movement of the dental implant system [4, 5]. The geometric patterns of the thread of implant that includes thread pitch, helix angle, thread depth are varied to alter the functional thread surface, which affects the stress

distribution at the bone-implant interface [6, 7]. Horiuchi et al. [8] proposed that implants ought to be of minimum 10 mm long to guarantee a high success rate.

The design of dental implant focuses to avoid stress concentrations in the supporting bone structure. It is observed that higher stress concentrations lead to bone loss and mechanical complications like fracture of abutment and restorative material [9]. Djebbar et al. [10] studied the effect of direction of application of force on dental implant and analyzed the stress distribution in implant and abutment. The results showed that the forces that are not normal to the tooth contribute to higher stress concentration. Hisam et al. [11] investigated pre molar tooth implant for stress distribution. The results indicated that higher degree of osseointegration led to higher stress concentration but lower strain. Pietro et al. [12] reported that screw geometry plays important role in stability of the implant. They also concluded that instability and improper installation of the implant were the major concerns that led to implant failure. Möhlhenrich et al. [13] investigated the relationship between implant geometry, bone density with its stability. The results indicated that diameter of implant has greater influence on stability in comparison to length of the implant. Sadollah et al. [14] used different grades of material dividing the implant into 10 parts and evaluated the mechanical properties, and from the results obtained, optimum gradient material suitable for dental implant was found. Vathsala et. al [15] evaluated and compared the stress distribution for various bio compatible material and suggested titanium as the best suitable material for dental implant.

Titanium (Ti), is widely used bio compatible material for various medical clinical purposes due to its favourable mechanical properties and better osseointegration. [16,17]. Considering the fact that there is need for improved implant design for a commercial dental implant, the current investigation focuses on in vitro study using three dimensional CAD modelling software and finite element analysis tool, to derive at an optimum implant design. The complexity of clinical situations of implant biomechanics can be easily mimicked using finite element method. The study involves finite element analysis of modified implant body design of selected standard thread pitch and varying helix angle, to study the effect of parameters on stability and stress distribution at the implant/bone interface. The implant made of titanium is investigated for its best suitability, considering the von mises stress criterion at implant and cortical bone interface. In this way, a limited component strategy was utilized to explore the impacts of thread shape and helix angle on the stress and strain dissemination of the peripheral bone, from biomechanics perspective.

2. MATERIALS AND METHODS

2.1 Model Design and FE Model Generation

Three-dimensional finite element models as per the grouping shown in Table 1, were built with Catia software and Ansys software to analyse the stress, strain and deformations in the implant structure. Each set of model contained crown, abutment, abutment screw and implant of 2.2 mm thread pitch with varied angle group of single, double and triple thread with constant moment of 0.2 Nm for different axial load (100-N, 150-N, 200-N and 250-N) applied to occlusal table of the crown.

Table 1: Finite Element Analysis Groups

Group Number	Group Name	Description	Component
1	Pitch Group	Standard Pitch	2.2 mm
2	Angle Group	Helix angles	Single threaded 2.2 mm pitch
			Double threaded 2.2 mm pitch
			Triple threaded 2.2 mm pitch
3	Material Group	Bio Compatible Material	Titanium



Figure 1: Configurations of Implants with Abutment.

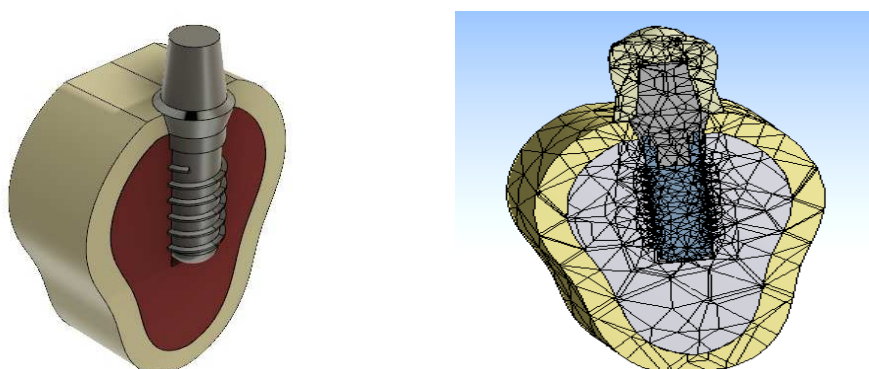


Figure 2: CAD and Meshed Model Showing Components of Dental Implant.

The Figure 1 shows the configurations of the implants with abutment considered in the study for analysis. The dental implant system was CAD modelled, with bone of dimensions representing the part of mandible of second premolar, as shown in Figure 2, and is meshed using finite element software. The d4.1 mm×12 mm implant model with the cortical bone thickness of 2mm was considered in the study [15].

2.2. Material Properties

The mechanical properties of the considered materials for the analysis were assumed to be homogeneous, isotropic, and linearly elastic are listed in Table 2. Frictional contact elements were used to represent the interface conditions between bones and implant surface.

2.3 Loads and Constraints

The model was constrained for all degrees of freedom, i.e. all directions at the bone surfaces. A constant moment of 0.2 Nm in anti-clockwise direction for different total vertical force of 100-N, 150-N, 200-N and 250-N was applied to occlusal surface of the crown.

Table 2: Mechanical Properties of Components of Dental Implant Structure

Component	Young's Modulus (Gpa)	Poisson Ratio	Source
Cancellous Bone	1.37	0.23	[16,17]
Cortical Bone	13.7	0.3	[17]
Crown (Porcelain)	68	0.35	[17]
Titanium	102	0.35	[17]

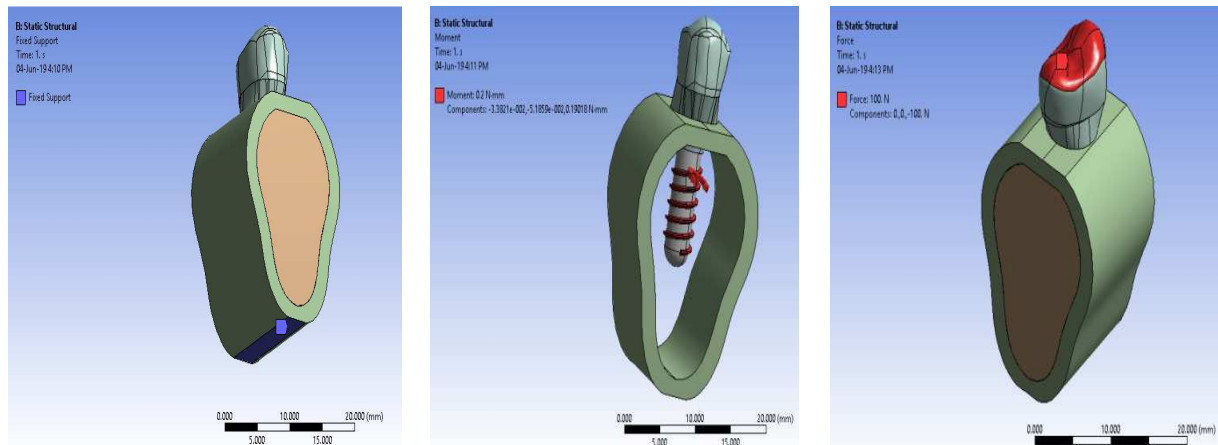


Figure 3: Boundary Conditions Applied on Dental Implant Structure.

Table 3: Mesh Convergence Test

Mesh Type	Nodes	Von Mises Stress in MPa		Total Deformation in mm	
		Maximum	Minimum	Maximum	Minimum
Coarse	145878	10.789	0.0376	0.00069	7.741e-5
Medium	224568	10.425	0.0376	0.00069	7.738e-5
Fine	332934	10.412	0.0376	0.00069	7.738e-5

2.4 FE Model Verification and Validation

The meshing of the designed model with tetrahedral elements, with each node having three degrees of freedom of the prosthetic system with coarse, medium and fine mesh with variable number of elements was performed. Further, the mesh element size was varied at the implant region, wherein there exists an interface of the implant with cortical bone. The convergence results were examined using the results of von mises stresses in cortical bone under a vertical loading condition to arrive at an optimal mesh size, with a tolerance of 1% considered. The Table 3 shows the mesh convergence test performed on dental implant structure and the variation in von mises stresses and number of nodes for coarse, medium and fine mesh, respectively. The numbers of elements and nodes were well refined in the models. The refined mesh of the crown restoration, abutment, screw, implant, and cancellous bone were all set to an element size of 0.5 mm, whereas the cortical bone was medium mesh size, and further analysis was performed.

3. RESULTS

The results obtained from the FE analysis for Von Mises stress distribution, total deformation and Von Mises stress for a titanium implant with 2.2 mm standard thread pitch and single, double and triple thread varied helix angle is shown in Table 4, Table 5 and Table 6, respectively.

Table 4: Distribution of Von Mises Stress, Total Deformation and Von Mises Strain in Restored Tooth (2.2 Mm Single Thread)

Groups	Particulars	Load (N)			
		100 N	150 N	200 N	250 N
Titanium (Ti)	Von Mises Stress (MPa)	16.65	24.97	33.30	41.62
	Total deformation (mm)	0.0007	0.0010	0.0013	0.0017
	Von Mises Strain	0.000154	0.000231	0.000308	0.000385

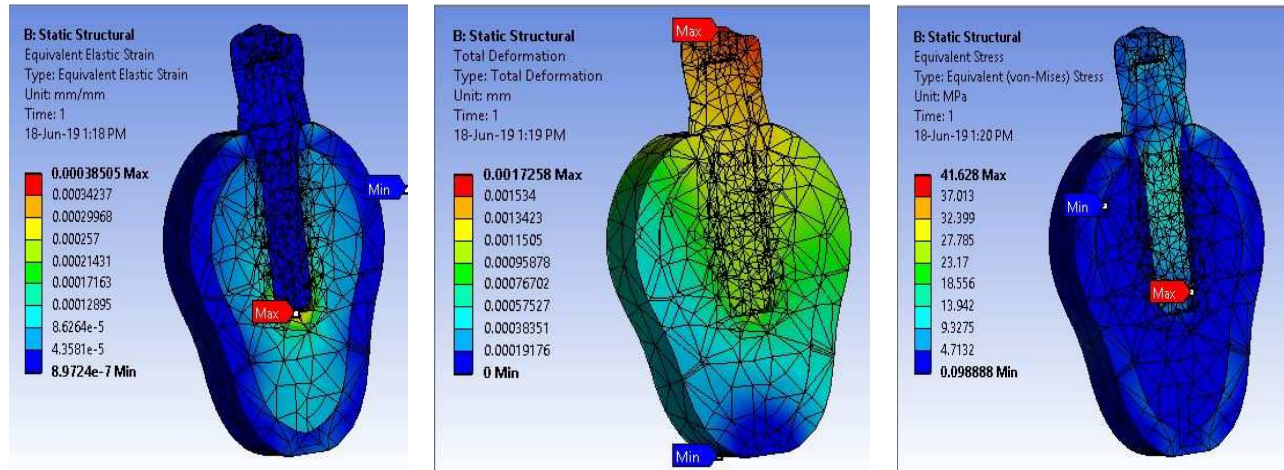


Figure 4: Von Mises Stress, Total Deformation and Von Mises Strain in Restored Tooth (2.2 mm Single Thread) – Titanium Implant.

Table 5: Distribution of Von Mises Stress, Total Deformation and Von Mises Strain in Restored Tooth (2.2 mm Double Thread)

Groups	Particulars	Load (N)			
		100 N	150 N	200 N	250 N
Titanium (Ti)	Von Mises Stress (MPa)	10.42	15.64	20.85	26.06
	Total deformation (mm)	0.0006	0.0009	0.0011	0.0016
	Von Mises Strain	0.000213	0.000320	0.000427	0.000534

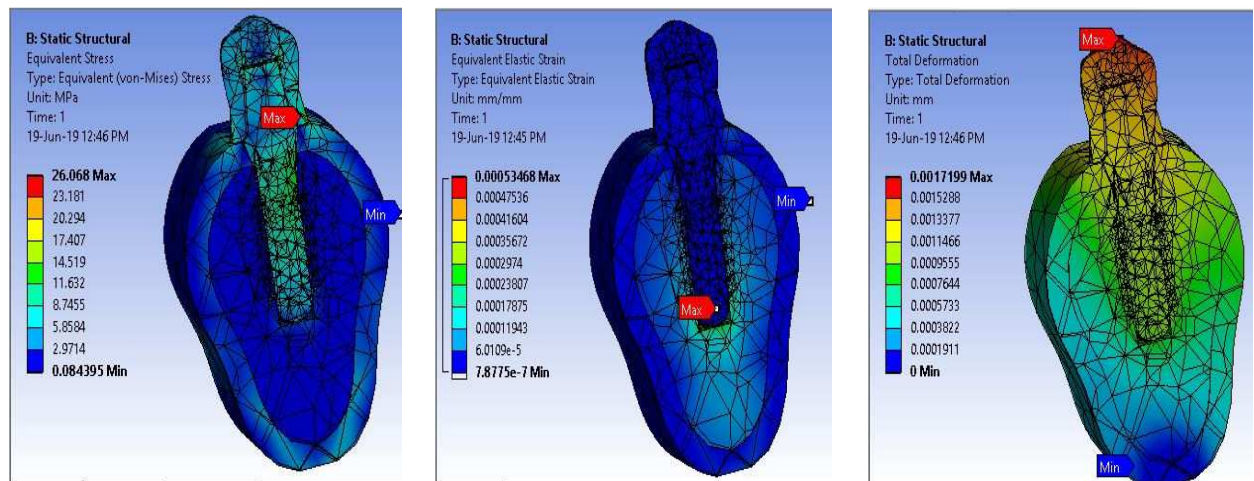


Figure 5: Von Mises Stress, Total Deformation and Von Mises Strain in Restored Tooth (2.2 mm Double Thread)–Titanium Implant.

Table 6: Distribution of Von Mises Stress, Total Deformation and Von Mises Strain in Restored Tooth (2.2 Mm Triple Thread)

Groups	Particulars	Load (N)			
		100 N	150 N	200 N	250 N
Titanium (Ti)	Von Mises Stress (MPa)	16.73	25.10	33.47	41.84
	Total deformation (mm)	0.0006	0.0010	0.0013	0.0017
	Von Mises Strain	0.000172	0.000258	0.000344	0.000431

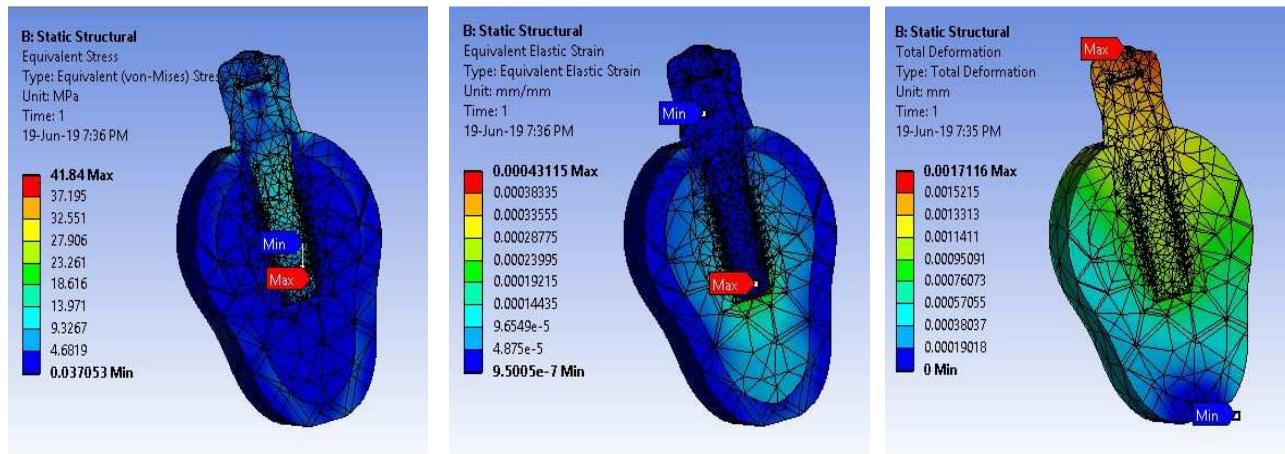


Figure 6: Von Mises Stress, Total Deformation and Von Mises Strain in Restored Tooth (2.2 Mm Triple Thread)–Titanium Implant.

Table 7: Distribution of Von Mises Stress in Cortical Bone Implant Interface

Groups		Particulars	Load (N)			
			100 N	150 N	200 N	250 N
Titanium	2.2 mm Single Thread	Von Mises Stress (MPa)	4.3	6.42	8.52	10.761
	2.2 mm Double Thread		4.24	6.35	8.17	9.26
	2.2 mm Triple Thread		5.34	6.95	9.33	11.64

The variation Von Mises stress, total deformation and Von Mises strain in restored tooth under applied boundary conditions in the dental implant system in different regions of interest is shown in the Figure 4, Figure 5 and Figure 6 for a titanium implant with 2.2 mm standard thread pitch and single, double and triple thread varied helix angle, respectively. The critical region of analysis for succesful restoration and faster rehabilitation is at the cortical bone and implant interface. Table 7 shows the distribution of Von Mises stress at the interface of cortical bone and implant

4. DISCUSSIONS

The stress distribution in the bone and the implant is significantly influenced by the implant material and implant design. In the present study, 3D finite element analysis (FEA) tool was used to evaluate the stress, strain and deformation in the implant made of titanium. The assumptions made in the study effect the accuracy of the results obtained. The bone is frequently modelled as isotropic material, whereas it is anisotropic [18]. Several researchers use FEA tool for mechanical analysis of the implants to model and simulate the clinical conditions [19]. The quality of mesh and element size influences the accuracy of the results obtained. In the earlier studies, it is observed that FEA software's like ABAQUS, ANSYS is predominantly used to mesh the model imported from CAD software [20]. However, for the complicated models, it is preferable to mesh using pre-processing meshing tool like Hypermesh and later imported in FEA software for analysis.

Sykaras et al. [21] investigated that, with the increase in the helix angle in single, double and triple threaded implants, it requires higher torque to maintain for better placement of implant and maintain tighter contact with the bone. However, it is observed that bone loses the pre-tension over the time due to its viscoelastic property, and hence higher torque is required to be maintained [22]. The results obtained suggest that helix angle plays a crucial role in implant stability. The stress distribution of implants with standard pitch of 2.2 mm with single, double and triple thread patterns (helix angles) compared. Under vertical load, the 2.2 mm pitch double threaded implant showed lower values of von mises

stress for the implant framework. In addition, a lower value of stress distribution at implant and cortical bone interface was observed. The comprehensive relative displacements was minimum for 2.2 mm pitch double threaded implant [23]. The results obtained are in agreement with the previous studies.

5. CONCLUSIONS

The finite element analysis helps to investigate the biomechanical response of dental implant system. The geometrical three-dimensional modelling of implant system is a challenge. In this research, a precise 3D geometrical implant system model is generated for varying helix angles. The implant with 2.2 mm double thread showed a minimum value of von mises stress and deformation under varied vertical loading conditions. The results obtained demonstrate that variation of helix angle affects the stability of loaded implant. The implant with lower stress values and deformation proves to have greater life and is successful.

6. CONFLICT OF INTEREST

All authors declare to have no conflict of interests.

7. ACKNOWLEDGEMENTS

Authors are grateful to Department of Mechanical and Manufacturing Engineering, Manipal Institute of Technology and Manipal College of Dental Sciences, Manipal, Manipal Academy of Higher Education for providing the lab facilities for the study.

REFERENCES

1. B. Friberg, G. M. Raghoobar, I. Grunert, J. A. Hobkirk, G. Tepper. (2008). A 5-year prospective multicenter study on 1-stage smooth-surface Brånemark system implants with early loading in edentulous mandibles, *Int. J. Oral Maxillofac. Implants* 23 (3) 481–486.
2. H. Martinez, M. Davarpanah, P. Missika, R. Celletti, R. Lazzara. (2001). Optimal implant stabilization in low density bone, *Clin. Oral Implants Res.* 12 (5), 423–432.
3. Miyamoto, Y. Tsuboi, E. Wada, H. Suwa, T. Iizuka. (2005). Influence of cortical bone thickness and implant length on implant stability at the time of surgery –clinical, prospective, biomechanical, and imaging study, *Bone* 37 (6), 776–780.
4. Gupta, I., & Saxena, G. (2014). Structural Analysis of Rotor Disc of Disc Brake of BAJA SAE 2013 Car through Finite Element Analysis. *International Journal of Automobile Engineering Research and Development (IJAuERD)* Vol, 4, 1–10.
5. O. Dilek, E. Tezulas, M. Dincel. (2008). Required minimum primary stability and torque values for immediate loading of mini dental implants: an experimental study in nonviable bovine femoral bone, *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.* 105 (2) e20–e27.
6. J. B. Brunski. (1988). Biomechanical considerations in dental implant design. *The International Journal of Oral Implantology*, vol. 5, no. 1, pp. 31–34.
7. Behari, A. L. K. A. (2014). Professional Development of Elementary Teacher Educators: Issues and Challenges. *Impact: International Journal of Research in Humanities, Arts and Literature*, 43–44.
8. J. P. Geng and X. X. Ma (1995). A differential mathematical model to evaluate side-surface of an Archimede implant, *Shanghai Shengwu Gongcheng Yixue*, vol. 50, article 19.

9. J. T. Steigenga, K. F. al-Shammari, F. H. Nociti, C. E. Misch, and H. L. Wang (2003). Dental implant design and its relationship to long term implant success," *Implant Dentistry*, vol. 12, no. 4, pp. 306–317.
10. K. Horiuchi, H. Uchida, K. Yamamoto, M. Sugimura. (2000). Immediate loading of Brånemark system implants following placement in edentulous patients: a clinical report, *Int. J. Oral Maxillofac. Implants* 15 (6) 824–830.
11. Sadek, H. A., Khami, M. J., & Obaid, T. A. (2013). Computer Simulation of Blood Flow in Large Arteries by a Finite Element Method. *International Journal of Computer Science and Engineering (IJCSE)*, 2(4), 171–184.
12. M. Akkocaoglu, S. Uysal, I. Tekdemir, K. Akca, and M. C. Cehreli. (2005). Implant design and intraosseous stability of immediately placed implants: a human cadaver study, *Clinical Oral Implants Research*, vol. 16, no. 2, pp. 202–209.
13. N. Djebbar, B. Serier, B. B. Bouiadjra, S. Benbarek and A. Draï. (2010). Analysis of the effect of load direction on the stress distribution in dental implant, *Mater. Design*, 31, 2097–2101.
14. M. J. Hisam, J. Y. Lim, D. Kurniawan and F. M. Nor. (2015). Stress distribution due to loading on premolar teeth implant, *Procedia Manufacturing*, 2 218–223.
15. P. Ausiello, P. Franciosa and D. Watts. (2012). Effect of thread features in Osseo integrated titanium implant using a statistics based finite element, *Dent. Mater.*, 28 (8), 919–927.
16. S. C. Möhlhenrich, N. Heussen, D. Elvers, T. Steiner, F. Hölzle and A. Modabber. (2015). Compensating for poor primary implant stability in different bone densities by varying implant geometry, *Int. J. Oral. Max. Surg.*, 44 (12), 1514–1520.
- A. Sadollah and A. Bahreininejad. (2011). Optimum gradient material for a functionally graded dental implant using metaheuristic, *J. Mech. Behav. Biomed.*, 4, 1384–1395.
17. Royanian, S., & Nozary, M. *Elements of Hope and Life in the Poetry of Farrokhzad and Plath*.
18. Vathsala P, D J Noronha, Nithesh N and Manjunath S. (2019). A comparative study on the effect of stress in dental implant structure using finite element analysis, *International Journal of Mechanical and Production Engineering Research and Development*, 9 (2), 709–717.
19. D. C. Holmes and J. T. Loftus. (1997). Influence of bone quality on stress distribution for endosseous implants. *J Prosthet Dent*, " *Journal of Prosthetic Dentistry*, vol. 23, pp. 104–111.
20. C.-L. Lin, J.-C. Wang, and Y.-C. Kuo. (2006). Numerical simulation on the biomechanical interactions of tooth/implant-supported system under various occlusal forces with rigid/non-rigid connections, *Journal of Biomechanics*, vol. 39, no. 3, pp. 453–463.
21. P. Chang, Y. Chen, C. Huang, W. Lu, and H. Tsai (2012). Distribution of micromotion in implants and alveolar bone with different thread profiles in immediate loading: a finite element study, *The International Journal of Oral & Maxillofacial Implants*, vol. 27, no. 6, p. e96.
- A. Fazel, S. Aalai, M. Rismanchian, and P. Sadr-Eshkevari. (2009). Micromotion and stress distribution of immediate loaded implants: a finite element analysis, *Clinical Implant Dentistry and Related Research*, vol. 11, no. 4, pp. 267–271.
22. J. T. Hsu, L. J. Fuh, D. J. Lin, Y. Shen, and H. Huang. (2009). Bone strain and interfacial sliding analyses of platform switching and implant diameter on an immediately loaded implant: experimental and three-dimensional finite element analyses, *Journal of Periodontology*, vol. 80, no. 7, pp. 1125–1132.
23. N. Sykaras, A. M. Iacopino, V. A. Marker, R. G. Triplett, and R. D. Woody. (2000). Implant materials, designs, and surface topographies: their effect on osseointegration: a literature review, *International Journal of Oral and Maxillofacial Implants*, vol. 15, no. 5, pp. 675–690.

24. T. Iyo, Y. Maki, N. Sasaki, and M. Nakata. (2004). Anisotropic viscoelastic properties of cortical bone," *Journal of Biomechanics*, vol. 37, no. 9, pp. 1433–1437.
25. N. Sasaki, Y. Nakayama, M. Yoshikawa, and A. Enyo. (1993). Stress relaxation function of bone and bone collagen, *Journal of Biomechanics*, vol. 26, no. 12, pp. 1369–1376.

AUTHORS PROFILE



DR NAYANA PRABHU is Associate Professor in the Department of Prosthodontics and Crown & Bridge and Coordinator of Manipal Implant Program. She has received her Master's degree from Manipal Academy of Higher Education, in 2006. She has more than 18 years of teaching experience in Dentistry. Her research interest includes the development of Implant Surfaces, Dental Materials and Prosthodontics. She is involved in the academic activities of the Undergraduate and Postgraduate students like Seminars, Journal Club discussions, Case discussions etc. and Guide for postgraduate dissertation studies. She has guided 7+ Undergraduate and Postgraduate students in research and project works. She has published several research articles in National and International Journals of repute.



NITHESH NAIK is faculty in Department of Mechanical and Manufacturing Engineering; He received his Master's degree from Manipal Academy of Higher Education, in 2012. He is currently pursuing the Ph.D. degree in Mechanical Engineering in the field of development of eco sustainable bio composites at Manipal Academy of Higher Education.

His research interest includes the development of Finite element analysis, composite materials and design and product development techniques. He has guided 30+ undergraduate and postgraduate students in research and project works.

He has published several research articles in International Journals of repute and has filed three patents at India Patents office for his innovations. He received award of South India's most exciting young teacher in the year 2017.



DR. VATHSALA PATIL is working as Assistant Professor in Department of Oral Medicine and Radiology, MCODS, Manipal. She completed her Master in Dental Surgery (MDS) from Manipal College of Dental Sciences, Manipal (Manipal Academy of Higher Education) in 2015.

Her research interests includes Early Diagnosis of potentially malignant lesions, Laser Spectroscopy, forensic science and Artificial Intelligence and its applications in dentistry.

She has seven publications to her credit in Scopus indexed journals. She has filed patent at India Patents office in June 2018 (KID A-Ray, with Application#: 306405)



UDIT RATHEE is an engineering graduate pursuing Bachelor of Technology in Mechanical Engineering from Manipal Institute of Technology. He is experienced powertrain engineer with a demonstrated history of working in the automotive industry.

His skillsets include Matlab, CATIA, Computer-Aided Design (CAD), ANSYS, and Keyshot. He is E-Powertrain Subsystem Head at Formula Manipal, Manipal Academy of Higher Education's official FSAE team. His research interests include the Finite element analysis, electric vehicle, battery technologies, thermal modelling and product development.

He has represented the team in various national events such as Formula Bharat and Formula Student Electrical vehicle concept challenge. He has published research article in International Journal and has applied for a patent on Automated Universal Gear Hobbing Fixture at India Patents Office.



AMINA BARKALLAH is an engineering graduate in Mechanical Engineering from National Engineering School of Bizerte, Tunisia.

Her skill sets include Matlab, CATIA, Computer-Aided Design (CAD), and ANSYS. Her research interests include the Finite element analysis, thermal modelling and product development. She underwent industrial training in the areas of petroleum refining. She has published several research articles in National and International Journals of repute.